[AUTHORS] [INDEX]

ASSESSING THE MERCURY HEALTH RISKS ASSOCIATED WITH COAL-FIRED POWER PLANTS: IMPACTS OF LOCAL DEPOSITIONS

***T.M. Sullivan[1], F.D. Lipfert[2], S.M. Morris[2], and S. Renninger[3]**
[1]Building 830, Brookhaven National Laboratory, Upton, NY 11973
[2]Private Consultants
[3]Department of Energy, National Energy Technology Laboratory, Morgantown, WV

ABSTRACT

The U.S. Environmental Protection Agency has announced plans to regulate emissions of mercury to the atmosphere from coal-fired power plants. However, there is still debate over whether the limits should be placed on a nationwide or a plant-specific basis. Before a nationwide limit is selected, it must be demonstrated that local deposition of mercury from coal-fired power plants does not impose an excessive local health risk. The principal health concern is exposure of pregnant females to methyl mercury in seafood.

This paper presents a quantitative assessment of the health risks for populations within 50 km of a power plant. Probabilistic risk assessments were performed for two power plants, Bruce Mansfield in western Pennsylvania and Monticello in eastern Texas. Local hourly meteorological data was obtained for these sites and deposition modeling was performed for a region 50 Km around the site. Risk assessments were performed for two population groups (general and subsistence fishers) and the modeled deposition patterns. The risk assessments indicated that for the general population local deposition associated with the emissions from the coal-fired power plant were small (< 10^{-5} risk of observed neurological effects) but risks could be two orders of magnitude higher for subsistence fisher populations. Estimated risks were more highly dependent on consumption patterns than increases in deposition due to coal-fired power plant emissions.

INTRODUCTION

Mercury contamination is a concern in the United States and many countries of the world. Forty-one states have fish consumption advisories due to mercury contamination. Mercury is a trace impurity in coal that is released to the atmosphere during combustion. Coal-fired power plants constitute the largest U.S. point source of anthropogenic mercury contributing approximately 1/3 of the anthropogenic mercury released in the U.S.

The U.S. Environmental Protection Agency (EPA) has announced plans to regulate mercury emissions from coal-fired power plants. However, there is still debate over whether the limits should be on a plant specific basis or a nationwide basis. The nationwide basis allows a Cap and Trade program similar to that for other air pollutants. A Cap and Trade program has the potential to be protective of human health while being more economically efficient than limiting releases from all power plants to a fraction of their current release rates. To address whether controls are needed on every coal-fired power plant or if a Cap and Trade program is appropriate, an evaluation of the impacts of local deposition of mercury on risk is needed. Some mercury emitted from the stacks of the power plants can deposit locally (within 50 km), potentially leading to higher concentrations in water bodies and fish, and therefore, higher risks associated with consuming mercury.

In this study, local deposition of mercury emitted from Bruce Mansfield and Monticello coal power plants was simulated. The code ISCST3 was used with mercury emissions data from the two power plants and local meteorological conditions to assess local deposition. The deposition modeling results were used to estimate the potential increase in mercury deposition above background that could occur in the vicinity of the plant and the risks of such exposure estimated.

Risk Assessment Approach

The endpoint used in this study is the population risk of a health effect due to exposure to mercury. This analysis requires data on the distribution of exposures to Hg and a dose-response function. The baseline risk assessment approach has the following steps:

- Estimate fish consumption from survey data
- Estimate Hg concentration in fish species from measured data.
- Estimate daily Hg intake as the product of consumption and concentration in fish.
- Use the dose response function to estimate risk.

Ideally, to get the population risk we need to repeat this process for each member of the population. In fact, the consumption of fish varies from person to person and the Hg concentration in fish varies between fish and between species of fish. Therefore, to get the population risk, a Monte Carlo approach is used that samples among the distribution of consumption behavior and the distribution of Hg concentrations in fish. The result is a distribution of daily intake. This distribution in intake is converted to a distribution in Hg in hair. The dose response function converts estimated hair Hg levels to risk and is used for each group and the results are summed to estimate the total population risk.

To examine the impacts of local deposition of Hg emissions from coal plants, the following additional steps are required:

- Estimate the local deposition of Hg emissions
- Correlate the increase in local deposition with increases in mercury levels in fish. Many processes are involved from deposition to uptake in fish. For example, the deposited mercury needs to undergo methylation, which depends on water characteristics and biotic processes, to enter and work its way up the food chain to the fish. It is likely that these processes are not linear. For simplicity, it is assumed that the percentage increase in local deposition near the coal-fired power plant corresponds to the same percentage increase in mean Hg levels in fish.
- Using the adjusted Hg levels in fish calculate risk.

Using this approach involves a number of assumptions resulting in uncertainties in the analysis. Although the general mercury cycle is well understood, the exact details are not. There are still large uncertainties in a number of areas that impact the risk assessment. These include the effects of:

- point sources (e.g. coal power plants) on local deposition

- anthropogenic global sources on deposition in the U.S.
- deposition on Hg loadings in water bodies,
- water body characteristics on methylation rates,
- Hg loadings in water bodies to concentrations in fish.

The next few sections provide the data and technical basis for the risk assessment.

MODELING OF LOCAL DEPOSITION OF MERCURY FROM COAL-FIRED POWER PLANTS

The local atmospheric transport of mercury released from the coal-fired power plants was studied to estimate the local impacts of mercury deposition. The Industrial Source Code (ISCST3) Short Term air dispersion model was utilized to model these processes. The algorithms used to in ISCST3 are described elsewhere in detail (EPA, 1995). This code is an updated version of the computer code used by the Environmental Protection Agency to examine local deposition from combustion sources in their report to Congress in 1998 (EPA, 1998).

Modeling deposition requires three key sets of parameters: source emissions rate, meteorological data, and deposition parameters. The following sections describe each of these in detail.

Emissions

In 1999, the EPA requested information from over 100 coal-fired units on the emissions of mercury. Subsequently, testing was performed to measure the release of three types of mercury (elemental Hg(0), reactive gaseous mercury (RGM – Hg^{+2}), and particulate-bound, Hg(p)) from the exhaust stacks of these plants. For this analysis, the data from the Bruce Mansfield Plant in Shippingport, PA (Table 1) and the Monticello Plant in Monticello, TX were used as the emissions source term. The total 1999 emission from Bruce Mansfield was 458 kg or 1.45 10^{-2} g/s. Total mercury emissions from the Monticello power station was 954 kg (0.03 g/s) in 1999. Monticello is the plant with the highest mercury emissions in the U.S. in 1999.

Table 1. Mercury speciation and release rates.

	Bruce Mansfield	**Monticello**
Percentage of Hg(0)	78.5	39.2
Percentage of Hg(+2)	19.7	60.4
Percentage of Hg(p)	1.8	0.3
Release Rate of Hg(0) (g/s)	0.0114	0.012
Release Rate of Hg(+2) (g/s)	0.0029	0.018
Release Rate of Hg(p) (g/s)	0.00026	0.000091
Total Hg Release Rate (g/s)	0.0145	0.03

Comparing the emissions rates indicates that both plants emit approximately the same amount of elemental mercury (Hg(0)), while the Monticello plant emits six times as much RGM and one-third as much particulate mercury as the Bruce Mansfield plant. These differences impact the amount of local deposition. The national average for emissions was 58% elemental mercury, 40% RGM, and 2% Hg(p). Thus, the Bruce Mansfield plant emits less RGM on a percentage basis than the national average, while the opposite is true for Monticello. The high emission rate and high fraction of RGM at the Monticello plant will lead to deposition estimates that should be an upper bound for all of the plants in the US.

Meteorological Data

The Bruce Mansfield plant is located in Shippingport, PA about 25 miles northwest of Pittsburgh, PA. Meteorological data from the Pittsburgh airport for the year 1990 were selected for use in the evaluation of deposition. Weather is variable, from year to year, and will change deposition amounts and patterns. The year 1990 was chosen for illustrative purposes and not with the intent of predicting deposition that occurred in a particular year. Data from 1999, the year of the emissions data, would have been preferable, but were not available. In 1990, the winds were primarily out of the south and west. The wind during precipitation events was more uniformly distributed in all directions. Rainfall was measured in 9.1% of the hours in the year. A total of 133 cm of precipitation was measured in 1990.

The Monticello plant is located in Monticello, TX about 9 miles south west of Mount Pleasant TX and about 100 miles east and north of Dallas, TX. Meteorological data from 1990 taken in Abilene was used as the basis for deposition modeling. The wind is almost always from due north or south, predominantly from the south (20% of the time). In contrast, precipitation events occur most frequently when the wind is out of the north. Southeasterly winds also account for times of substantial rainfall. Rainfall occurred approximately 4% of the time with a total amount of 80 cm.

Deposition Parameters

Once emitted from the stack, mercury can deposit through wet or dry processes. The rate of deposition depends strongly on the type of mercury. Particulate mercury is readily removed by rain. Reactive gaseous mercury and the compounds it forms also have a high solubility in water and are readily incorporated into precipitation. Elemental mercury has a low solubility and does not tend to accumulate in rain to the degree as the other two types of mercury. Dry deposition also depends strongly on the type of mercury. In general, reactive gaseous mercury deposits at a higher rate per unit mass than particulate mercury or elemental mercury due to its higher chemical reactivity with particulate surfaces.

In this analysis, the distribution of mercury between the three different conditions was assumed to equal that measured at the exhaust stack. It is recognized that this is a simplification of reality, as the ratio is likely to change as the distance from the stack increases due to chemical reactions in the plume. Recent work suggests that much of the RGM will change to elemental Hg within 50 km of the stack.

Wet Deposition

ISCST models wet deposition using rainfall intensity and an empirical parameter known as the scavenging coefficient. The total flux to be deposited is the product of the scavenging ratio multiplied by the concentration averaged over the vertical dimension. Scavenging ratios similar to those used for the calculations in the EPA report to Congress (EPA, 1998) were used in this analysis (Sullivan, 2003). Particle deposition rates depend on the particle size. In this study, particle size distributions obtained by Landis were used for estimating deposition (Landis, 1998). Two particle sizes were used in the analysis. The particle diameter for the fine fraction was 0.68 μm. The coarse fraction particle median diameter was 3.5 μm. Wet deposition parameters are summarized in Table 2.

Table 2. Wet Deposition Parameters.

Form of Mercury	**Liquid Scavenging Coefficient $(s\text{-}mm/hr)^{-1}$**	**Frozen Scavenging Coefficient $(s\text{-}mm/hr)^{-1}$**
Hg(0)	3.310^{-7}	$1.0\ 10^{-7}$
Hg(+2)	$2.5\ 10^{-4}$	$5.0\ 10^{-5}$
Hg(p) 0.68 μm	$7.0\ 10^{-5}$	$2.0\ 10^{-5}$
Hg(p) 3.5 μm	$2.8\ 10^{-4}$	$5.0\ 10^{-5}$

Dry Deposition

Dry deposition is frequently modeled using a deposition velocity. In general, the dry deposition velocity is a function of ground cover (e.g. grass, forests, water, etc.) and weather conditions. The total deposition flux is the product of the deposition velocity and the concentration at the ground surface. In the EPA Report to Congress on Mercury, dry deposition velocities were calculated over a range of conditions and the average deposition velocity for elemental mercury was 0.06 cm/s while for reactive gaseous mercury the average value is 2.9 cm/s (EPA, 1998). Particle deposition also depends on the size of the particles, with larger particles falling at their gravitational settling velocity which is controlled by their size and friction factors and smaller particles at a slower rate. Particle deposition velocities from Landis (Landis, 1998) were used in the analysis. The simulations used a deposition velocity of 0.09 cm/s for the 0.68 μm particles and 0.45 cm/s for the 3.5 μm particles.

Coal Plant Parameters

In order to run, ISCST, the stack height, stack exhaust temperature, and stack exit diameter and velocity are required. Stack exhaust temperatures were measured as part of the information collection request. The other data were selected to be consistent with the values used for large coal-fired power plants in the EPA's report to Congress (EPA, 1998) and are reported in Sullivan, 2003.

LOCAL DEPOSITION MODELING RESULTS

The data presented above were used to predict the amount of local deposition around the Bruce Mansfield and Monticello power plants. In the simulations the concentration of mercury in air (ng/m^3), wet deposition ($\mu g/m^2/yr$) and dry deposition ($\mu g/m^2/yr$) were computed on a 1 km grid centered on the plant. Air concentrations were available in terms of a yearly average value as well as peak values over a 24 hour period. Simulations were carried out for a minimum of 30 km in the downwind direction.

For a comparison basis, this study will use an air concentration value of 1.7 ng/m^3, the value used in the EPA Report to Congress for rural areas; wet deposition of 10 $ug/m^2/yr$, based on Mercury Deposition Network Data; dry deposition of 10 $ug/m^2/yr$; based on average literature estimates; and a total deposition of 20 $ug/m^2/yr$ as typical background levels.

Bruce Mansfield Local Deposition Results

Local deposition modeling was performed for the Bruce Mansfield plant using the data presented above. Air concentrations of Hg peak several kilometers to the east and northeast of the plant, consistent with the prevailing winds. The peak value is 0.015 ng/m^3, less than 1% of the expected background concentration, 1.7 ng/m^3. The predicted concentration values are at ground level, therefore, values near the centerline of the plume will be higher. The maximum daily average ground-level concentration was 0.13 ng/m^3, approximately 8% of the expected background. This indicates that even in the immediate vicinity of a power plant, the ground-level concentrations are only a small fraction of background levels.

Away from sources, the amount of reactive gaseous mercury is typically 1 – 3% of the total amount of mercury. Thus, background values of RGM are expected to range between 0.02 and 0.05 ng/m^3. Near the Bruce Mansfield Plant predicted RGM values average 0.0025 ng/m^3, approximately 1/10 of the background level.

Although only 20% of the mercury emitted is in the form of RGM (Hg^{+2}), 84% of the wet deposition is RGM. In contrast to the concentration plume, the wet deposition is located almost uniformly around the plant with excess deposition of 5 $ug/m^2/yr$ extending no more than 10 km from the plant. Deposition is primarily along the east-west plane consistent with the predominant winds during precipitation. The estimated background wet deposition rate is 10 $ug/m^2/yr$, thus a region near the plant is predicted to have deposition two to three times the assumed background wet deposition.

RGM contributes approximately 85% of the total dry deposition even though it is only 20% of emissions. The deposition pattern reflects the concentration pattern and peaks to the east of the facility consistent with the prevailing winds. Total deposition rates are much lower than for wet deposition, but they are distributed over a much greater area. The fact that the peak is away from the plant results from the emission at elevated temperature and height. Figure 1 presents the total predicted deposition pattern around Bruce Mansfield plant. The pattern is dominated by wet deposition near the plant. Dry deposition never exceeded 4 $ug/m^2/yr$.

Table 3 summarizes the total mass deposited and the average deposition rate over the modeled area for each of the three forms of mercury. The total mass deposited over the modeled domain is predicted to 8800 grams or 1.9% of the total emitted. This indicates that the vast majority of mercury emitted from the Bruce Mansfield plant is not deposited within 30 km of the plant and enters the global mercury cycle. In the emissions, elemental mercury accounts for 78.5% of the mass, RGM accounts for 19.7% and particulate mercury accounts for 1.8%. In the deposition, RGM accounts for 84% of the total deposition, elemental mercury accounts for 11% and particulate mercury accounts for 5%. The higher relative deposition rates of RGM and particulate mercury reflect the higher values for their deposition parameters. Their fractional deposition rate (mass deposited over the modeled domain

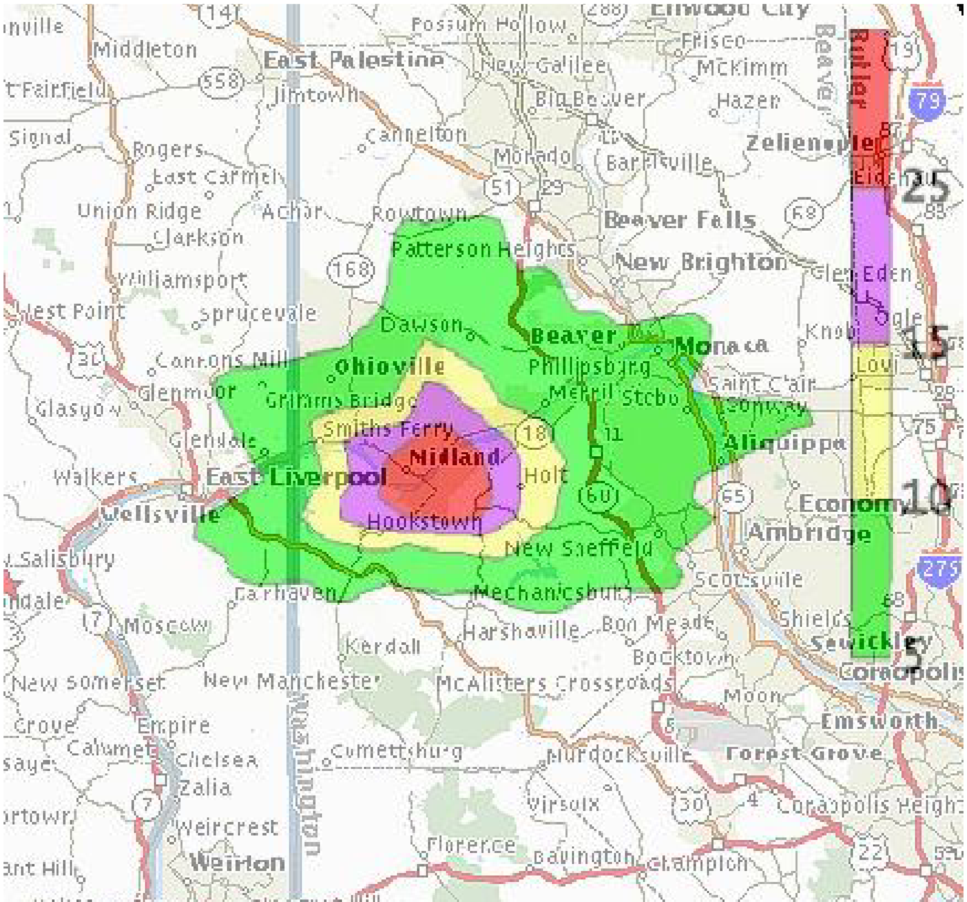

Figure 1. Total predicted deposition (ug/m^2/yr) around the Bruce Mansfield Power Plant.

Table 3. Bruce Mansfield Mercury Deposition summary.

	Hg(0)	**Hg(+2)**	**Hg(p)**	**Total Hg**
Total Mass deposited	BRMANHGP	BRMANRGM	BRMANHG0	
Wet deposition (g)	646	3808	156	4610
Dry deposition (g)	300	3559	306	4165
Total deposition (g)	946	7367	462	8775
Avg deposition rate				
Avg Wet Deposition (μg/m^2/yr)	0.026	1.5	0.063	1.6
Avg Dry Deposition (μg/m^2/yr)	0.012	1.4	0.012	1.4
Avg Total Deposition	0.038	2.9	0.075	3.0
Fractional Deposition				
Fraction of Wet Deposition to Emissions	$1.9\ 10^{-3}$	0.034	0.02	0.01
Fraction of Dry Deposition to Emissions	$8.9\ 10^{-4}$	0.031	0.039	0.009
Fraction of Total Deposition to Emissions	$2.8\ 10^{-3}$	0.065	0.059	0.019

divided by the mass emitted from the plant) was around 6%, while less than 0.3% of the elemental mercury deposited locally. Although, the peak deposition rates are much higher for wet than dry deposition, the total mass deposited by each mechanism is approximately the same. The area average deposition rate from plant emissions, 3.0 $ug/m^2/yr$, is approximately 15% of that expected from background (20 $ug/m^2/yr$). This number, 15%, is used in the risk assessment to evaluate the impacts of local mercury deposition on health risk. Around the plant, there is an area of approximately 50 km^2 that receives an average deposition rate of 20 $ug/m^2/yr$. In this region, deposition is doubled over background and this value will be used to examine an upper bound on the potential increases in risk due to local deposition of mercury.

Monticello Deposition

Local deposition modeling was performed for the Monticello plant using the data presented above. The Monticello plant emitted twice as much mercury as the Bruce Mansfield plant and had the highest total emissions in the U.S. for 1999. In addition, it emits over 60% RGM, thus local deposition is expected to be among the highest of all U.S. plants. Air Hg concentrations peak to the north of the plant consistent with the prevailing southerly winds. The peak value is 0.04 ng/m^3, less than 3% of the expected background concentration, 1.7 ng/m^3. However, the peak annual RGM concentration is 0.022 ng/m^3, which is approximately the same as the expected background level of RGM. The maximum daily average Hg concentration was 0.58 ng/m^3, approximately 34% of the expected background. This indicates that even in the immediate vicinity of the power plant with the largest emissions in the US, the increase in air concentrations are only a fraction of background levels.

Over 98% of the wet deposition arises from reactive gaseous mercury. This is due to the large fraction of RGM (60%) in the emissions and the large deposition parameters relative to elemental mercury. Due to the wind flow being almost exclusively in the north-south direction, the wet deposition is located along this axis. The large amount of RGM in the emissions leads to high predicted deposition rates. Wet deposition is predicted to be greater than 40 $ug/m^2/yr$ (4 times wet deposition background) for a distance of five kilometers from the plant in both the north and south directions.

Due to the different dry deposition velocities, RGM contributes approximately 98% of the total dry deposition even though it is only 60% of emissions. The deposition pattern peaks to the north of the facility consistent with the prevailing winds. Total deposition rates are in excess of the estimated background dry deposition rate of 10 $ug/m^2/yr$ for almost 50 km from the plant. The fact that the peak is away from the plant results from the emission at elevated temperature and height

Figure 2 shows the total predicted deposition around the Monticello power plant. The deposition is peaked along the north-south axis, which is the direction of wind flow.

Table 4 summarizes the total mass deposited and the average deposition rate over the modeled area around the Monticello plant for each of the three forms of mercury. The total mass deposited over the modeled domain is predicted to be 23,400 grams or 2.5% of the total emitted. Increasing the distance to a 50 km radius around the plant did not change the predicted wet deposition. However, the dry deposition mass increased by a factor of 3 to 29,100g. The total deposition within 50 km of the plant was 40,100 grams, 4.2% of the total emitted. This indicates that the vast majority of mercury emitted from the Monticello plant is not deposited within 50 km of the plant and enters the global mercury cycle. In the

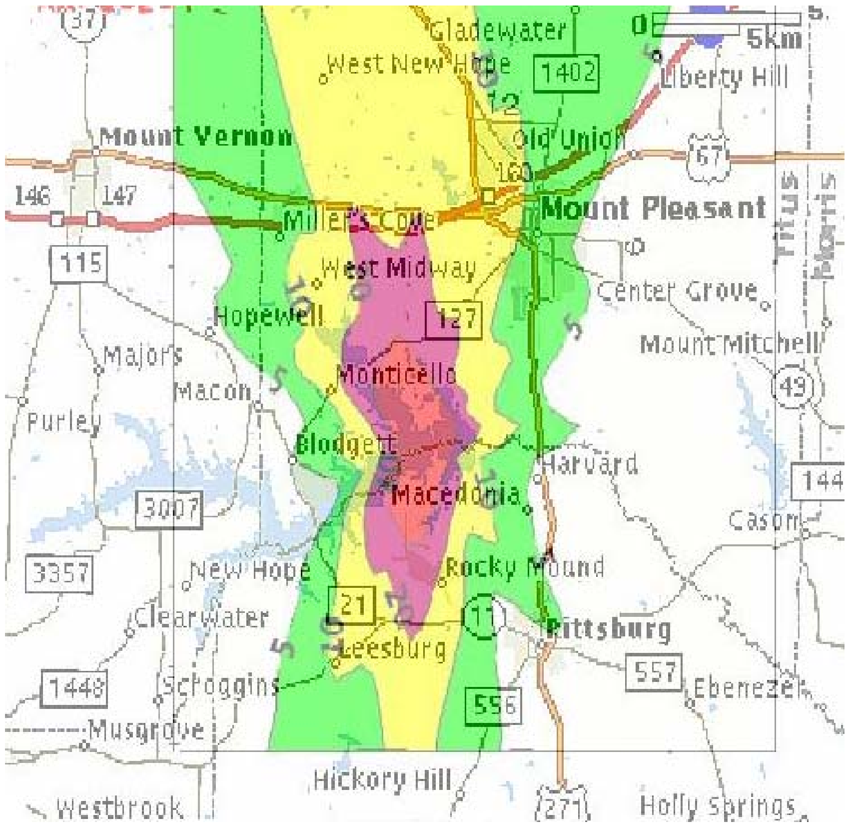

Figure 2. Predicted total Hg deposition around the Monticello power plant. (red – 40 ug/m^2/yr, purple –20 ug/m^2/yr, yellow – 10 ug/m^2/yr, and green – 5 ug/m2/yr).

emissions, elemental mercury accounts for 40% of the mass, RGM accounts for 60% and particulate mercury accounts for 0.3%. In the deposition, RGM is responsible for 98.7% of the total deposition, elemental mercury accounts for 1.1% and particulate mercury accounts for 0.2%. Their fractional deposition rate (mass deposited over the modeled domain divided by the mass emitted from the plant) was around 4%, while less than 0.07% of the elemental mercury deposited locally. Over the modeled area, 50 X 50 km rectangular grid, the average deposition rates for wet and dry deposition are similar and around 4.5 ug/m^2/yr. The area average deposition rate over this area, 9.30 ug/m^2/yr is approximately 45% of that expected from background (20 ug/m^2/yr). This percentage increase is used in the risk assessment to evaluate the impacts of local deposition. However, regions of this area along the prevailing wind direction were in excess of 20 ug/m^2/yr. Within 10 km of the plant in this direction, predicted deposition exceeded 40 ug/m^2/yr, or twice the expected background. Evaluation of the predicted deposition in the area bounded by the 20 ug/m^2/yr contour suggested that average mercury deposition in this region could be 33 ug/m^2/yr, or 1.65 times background. As an upper bound estimate of the local deposition, an increase of 165% over background was used in the risk assessments. The Monticello plant is expected to be an upper bound on deposition from coal-fired power plants due to the large emission rate (highest in the US, almost 2% of total US emissions), high fraction of RGM (60%, US average 34%) and meteorological conditions (wind almost exclusively from the South).

Table 4. Monticello mercury deposition summary.

	Hg(0)	Hg(+2)	Hg(p)	Total Hg
Total Mass deposited				
Wet deposition (g)	39	11681	39.5	11759
Dry deposition (g)	218	11378	2.8	11599
Total deposition (g)	257	23059	42.3	23358
Avg deposition rate				
Avg Wet Deposition ($ug/m^2/yr$)	0.015	4.7	0.016	5.0
Avg Dry Deposition ($ug/m^2/yr$)	0.1	4.5	0.001	4.6
Avg Total Deposition	0.11	9.2	0.016	9.3
Fractional Deposition				
Fraction Wet Deposition to Emissions	0.0001	0.021	0.014	0.013
Fraction Dry Deposition to Emissions	0.0006	0.02	0.001	0.012
Fraction Total Deposition to Emissions	0.0007	0.04	0.014	0.025

Summary of Deposition Modeling

Major findings of the deposition modeling are:

- Wet deposition removes a large fraction of the reactive gaseous and particulate mercury emitted during precipitation events and this deposits locally within 5 or 10 km of the plant. Although, most of these types of mercury emitted during precipitation events are deposited locally, precipitation events occur less than 10% of the time, therefore, only 2 – 4% of the RGM is deposited due to wet deposition.
- The total amount of RGM deposited locally under dry conditions is predicted to be approximately the same as for wet deposition. Dry deposition rates of RGM are lower than wet deposition rates, but occur over a larger area.
- Only a few percent (4 – 7 %) of the mercury emitted from the power plants deposits within 50 km of the plant.
- Reactive gaseous mercury is the primary form of mercury that is deposited.
- In the prevailing wind direction, deposition resulting from coal plant emissions can be the same level as expected background deposition.

RISK ASSESSMENT

The objective of this study is to quantify the impact of local mercury deposition from coal-fired power plants on risks from fetal exposure through maternal consumption of fish. Based on the data collected in the 1999 EPA data collection request, we used the mercury emissions data from two power plants, Monticello in eastern TX, and Bruce Mansfield in Shippingport, PA, as the basis for modeling local deposition.

Increase in Fish Mercury levels due to local deposition

In assessing the impacts of local deposition of Hg from coal power plants on Hg levels in fish, we are most interested in local freshwater fish consumed by the population. Marine fish such as tuna, swordfish, shellfish, etc., will be largely unaffected by changes in U.S. emissions in Hg. Less than 1% of the global total Hg emissions result from coal-fired plants in the U.S. Therefore, it is likely that completely stopping Hg emissions from coal plants in the U.S. would lead to less than a 1% decrease in Hg levels in marine fish. In this study, the Hg level in marine fish is held constant. For freshwater fish, an assumption is made that an increase in deposition leads to a linear increase in mercury levels in fish. Recent studies suggest that this is likely to be a conservative upper bound on increases in mercury concentration. A study by Bucholtz, 2002 did find a statistically valid correlation between anthropogenic sources and mercury levels in fish. There results showed that a 10% decrease in local sources would lead to a 0.6% decrease in fish mercury content. A USGS study suggests that the formation of methyl mercury increases logarithmically with total loading (Krabbenhoft, 1999). However, the authors acknowledge that the data they collected are insufficient to rule out the possibility that at low mercury loadings the relationship between deposition and methyl mercury production may be linear.

Dose Response Function

The basis for determining the dose response function for Hg exposure is three separate epidemiological studies conducted in the Seychelles, Faroe Islands, and New Zealand during the 1990's and discussed in detail in the National Academy of Sciences report (NAS, 2000). These epidemiological studies were conducted on populations that had high consumption of seafood and therefore, high mercury levels in hair and other biomarkers. They all evaluated the impacts of Hg exposure to children and the measures of impact involved a series of tests of cognitive abilities (copying errors, language skills, etc) in terms of a benchmark dose (BMD). The benchmark dose is the estimated dose corresponding to a specified incremental percentage of poor performers in a given test over and above background. EPA has taken the specified increment to be 5%.

In this study, Monte Carlo sampling among the 16 BMDs and their associated distributions was performed and the resulting pooled BMD and the pooled distribution results in a dose response function (DRF) that is a measure of the probability of a 5% increase over background in observing **any** of the various health endpoints at a given exposure level. The details of this process and the advantages of using pooled data to estimate the dose response function were reported in Sullivan, 2003.

RISK ASSESSMENT TEST CASES AND RESULTS

The risk assessments performed for this analysis include three different test cases for each plant and two population groups. For the general population, a unique fraction of consumption of local fish was used based on data for the region. The population near the Bruce Mansfield plant consumes 17% locally caught fish, similar to the average value in the northeast and the population near the Monticello plant consumes 22% locally caught fish, similar to the average value for the Southeast of the United States (Jacobs, 1998). Subsistence fishers are assumed to consume 100% locally caught fish. For subsistence fisher populations, two different consumption patterns were selected. For the population, near the Bruce Mansfield plant, consumption was based on data collected by Stern for women of child bearing age in New Jersey (Stern, 1996). For the population near the Monticello plant, subsistence fisher consumption rates were based on values obtained for a study along the Savannah River (Burger, 1998). While these consumption data are not an exact match for the locations under study, they are believed to be useful for illustrative purposes. Subsistence fishers that consume only locally caught fish are expected to be a small part of the total population (less than 1%).

From the deposition modeling, the average increase in deposition as compared to a background deposition rate of 20 ug/m^2/yr over the 2500 km^2 around the plant was 15% at Bruce Mansfield and 46.5% at Monticello. Over an area that is 50 – 100 km^2, immediately adjacent to the plant, deposition doubled at Bruce Mansfield and increased by a factor of 2.65 near the plant. These increases in deposition were used to estimate potential increased risks.

Table 5 summarizes key fish consumption and risk assessment parameters used in the analysis. The table provides the base case level. Therefore, if the plant emissions double local deposition, the fish concentration of mercury would be similarly doubled and the risks computed. The consumption rates and fish mercury content in Table 7 are mean values and their associated standard deviation. For the Monte Carlo analysis, a lognormal distribution of the data was assumed using these parameters. The mean consumption rates in the table are the US average and the estimated values for subsistence fishers near the plants.

Table 5. Key parameters for fish consumption and uptake.

	Mean Hg (ppm)*	Mean Consumption (g/d)*	General Population		Subsistence Fisher Population	
			% of Freshwater Fish	% of Saltwater Fish	% of Freshwater Fish	% of Saltwater Fish
US Average	0.21 (0.15)	18 (37.3)	N/A	N/A	N/A	N/A
Near Bruce Mansfield	0.41 (0.82)	41 (32.5)	17	83	100	0
Near Monticello	0.53 (0.47)	76.8 (67.6)	22	78	100	0

.* Numbers in parenthesis are the standard deviations for the distributions used in Monte Carlo analysis.

Population Risk Assessment Results near the Bruce Mansfield Power Plant

For each test case, 20,000 simulations using Latin Hypercube sampling were performed to explore the impacts of the variability in consumption, Hg levels in fish, and the conversion of consumption rate to Hg levels in hair. The resulting population distribution of hair Hg was used to estimate population risks using the average of the log-weighted dose response factor (Sullivan, 2003).

Figure 3 presents the distribution of predicted hair mercury for the general population under background deposition (base case) and for doubling of background deposition, which is predicted to occur within a few km of the power plant. The figure also presents the log-weighted dose response factor. The dose response factors represent the probability of having a 5% chance of an adverse effect. The population risk is the product of the DRF and the percentage of people at a given mercury level. The figure clearly illustrates that doubling of deposition has only a minimal impact on predicted hair mercury and therefore health risks. The figure also highlights that only a very small percentage of people bear the risks as less than 0.1% of the people have hair mercury levels in excess of 8 ppm, where the DRF suggests that the risk to the individual is around 10^{-3}.

For the general population group near the Bruce Mansfield plant, this risk ranges from 1.1 10^{-5} assuming no additional exposure from the plant (base case) to 6.7 10^{-5} in going from the base case to a doubling of deposition. The predicted doubling of deposition occurs over a small region (50 km^2) and thus, will not affect large numbers of people. Over the 50 km square region around the plant (2500 km^2 area), the average mercury deposition increases by 15% over background and the estimated risk is 1.9 10^{-5}, less than double the base line risk.

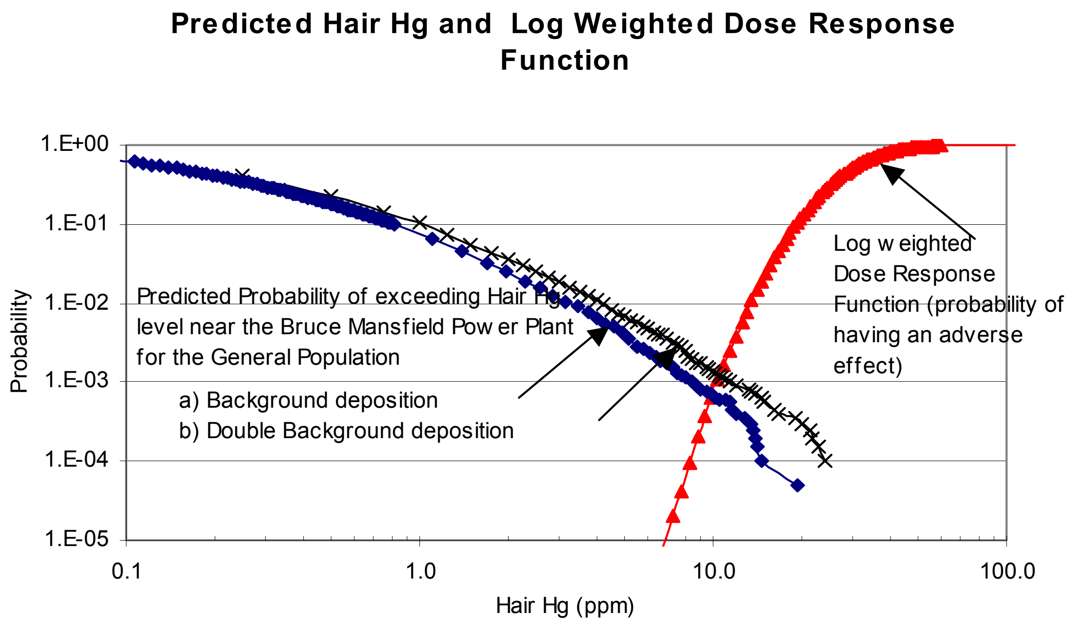

Figure 3. Predicted Hair Hg for the general population for background and double deposition scenarios contrasted with the log weighted dose response function.

For the subsistence fisher, risks are much greater due to their higher consumption rates, more than double the general population near Bruce Mansfield, and the consumption of only locally caught fish, which has twice as much mercury per unit mass as the average for saltwater fish. Predicted risks range from 2.9 10^{-3} in the base case, to 9.5 10^{-3} for doubling the deposition near the power plant. This is a result of the higher fraction of subsistence fishers with predicted hair Hg in excess of 10 ppm where risks begin to become appreciable. Risks are much more associated with consumption patterns than with deposition patterns. For the subsistence fishers, the risk is borne by the top 5% of this distribution. Considering that this group most likely represents much less than 1% of the total population, it can be inferred that less than 0.1% of the total population are potentially at risk of having a 5%

chance of an adverse effect. Table 6 summarizes the calculated risks and presents the predicted hair concentrations at the mean, 95, 99, and 99.9 percent exposure level.

Table 6. Summary of Risks and Predicted Hair Hg Levels for the population near the Bruce Mansfield Power Plant.

Case	Population Risk	Hair Hg (ppm)			
		99.9%	99%	95%	Mean
General Population					
Base	1.10E-05	8.7	3.2	1.3	0.36
High Fish consumers	2.90E-05	10.1	5	2.7	0.93
15% Extra Deposition	1.90E-05	9.6	3.6	1.3	0.37
Near Plant double deposition	6.70E-05	14.9	4.1	1.6	0.46
Subsistence Fishers (All local fish)					
Base	2.90E-03	49.9	15.2	5.7	1.5
15% Extra Deposition	5.00E-03	72.3	17.1	6.2	1.6
Near Plant double deposition	9.50E-03	96.6	28.6	10.9	3.0

A few important observations of the analysis:

- The risks of an effect are small to the general population. 99.9% of the general population is predicted to be below 11 ppm even under a 15% increase in deposition. Slightly more than 0.1% of the population will exceed 11 ppm if the local deposition doubles background deposition.
- In all cases, in the general population, the risks are primarily borne by individuals at the high end of the distribution (top 0.1 percent which implies individuals within the distribution that are high fish consumers and consume fish with high mercury content).
- The risk from high level fish consumers (mean intake 40 g/d) at the background deposition rate exceeds that of the general population living within 50 km of the plant and experiencing 15% increase in deposition.
- Even doubling the deposition does not pose a large risk to the general population. The risk of having a 5% chance of seeing an adverse effect is 6.7 10^{-5}.

Population Risk Assessment Results near the Monticello Power Plant

The results of the local deposition modeling near the Monticello Power Plant were conceptually similar to those at the Bruce Mansfield Plant. Due to the higher mercury, particularly reactive gaseous mercury, and emission rates from the plant, the risk estimates were slightly greater at the Monticello Plant. The risks to the general population are low ranging from 1.2 10^{-5} in the base case to 9.0 10^{-5} under the assumption that the plant increases local deposition by 165% from 20 ug/m^2/yr to 53 ug/m^2/yr. This high rate of deposition is expected to occur only within 10 km of the plant. It is interesting to note that if the assumption of a linear increase in deposition leads to a linear increase in fish Hg levels, the predicted fish average mercury level for this deposition rate increases from 0.53 ppm to 1.4 ppm, well in excess of any regulatory limit for issuing fish consumption advisories. Even with this exceptionally high average Hg level in fish, the general population risks of having a 5% chance of an adverse effect are 9.0 10^{-5}.

The risks for subsistence fishers near Monticello are much greater than for the general population and range fro 6.3 10^{-3} for the background deposition, 2.2 10^{-2} for a 46.5% increase in deposition, to 5.5 10^{-2} when this deposition is increased 165%. However, for both the general population and subsistence fishers the incremental risk associated with local deposition ranges from 0.4 to 7.7, times the baseline risk. The risks for having a 5% chance of an observable effect for the subsistence fisher at the background deposition rate is 0.6%, much greater than for the general population at a deposition rate 2.65 times greater than background. This indicates the risks are much more sensitive to consumption patterns than deposition patterns. Although risks are on the order of a few percent for subsistence fishers under increased mercury deposition from the power plant, it must be recognized that they comprise only a small fraction of the general population.

Discussion and Assumptions

The preceding analysis suggests that the population risk to the general population from local deposition of mercury form coal-fired power plants is small. The analysis suggests that a few percent of subsistence fishers that consume only locally caught fish and in large quantities may have some risk. These analyses were performed with the intent of overestimating risks, however, due to the large number of assumptions and uncertainties in the analysis, it is difficult to determine if this objective has been achieved. Uncertainties arise from the following assumptions:

- That water bodies of sufficient size to support large numbers of subsistence fishers are near the power plant.
- That a linear increase in deposition implies a linear increase in fish mercury content. Data suggests that the increase would be less than linear (Bucholtz, 2002).
- The consumption patterns for subsistence fishers are appropriate. They are considerably higher than the EPA's Reasonable Maximum Exposure freshwater fish consumption rate.
- That estimates of baseline fish concentrations, consumption rates, and fraction of freshwater and saltwater fish consumption are appropriate for the population groups studied.
- That use of meteorological data from nearby locations is representative of the sites modeled.
- That the pooled dose response functions are appropriate measures for risk of having an adverse effect.
- That speciation fractions from the plants based on short-term tests are appropriate for the entire year.

CONCLUSIONS

The objective of this study was to examine the human health risks that may occur due to local deposition of mercury arising from coal-fired power plants. As part of this assessment, an evaluation on whether local impacts are large enough to warrant mercury emission controls on a plant by plant basis or on a nationwide basis (cap-and-trade) program was appropriate. To accomplish this, risk assessments have been performed to examine the impacts of local deposition of mercury. Two plants were selected for analysis. These plants, Bruce Mansfield and Monticello, are characterized by high total mercury emission and, in the Monticello case, high reactive gaseous mercury, and therefore, are expected to be on the upper end of coal plants in terms of their local deposition. Modeling indicated that deposition over a 50 km square region around the plant could increase by 15 – 47%. Due to wet deposition of mercury, a small region (5 – 10 km) around the plant could experience increases in deposition rates by 100 – 165% of background. Yearly average concentrations of mercury in air resulting from the emissions from the coal plant were a fraction of expected background concentrations. Concentrations directly in the emissions plume near the plant will be higher.

Risk assessments were performed for three deposition rates at each plant, background, average increase over the 50 km region around the plant as determined from deposition modeling, and average increase over a small zone near the plant. In addition, two population groups were considered. The general population that consumes approximately 80% saltwater fish and 20% locally caught freshwater fish and a subsistence fisher population that consumes more fish than the general population and consumes only locally caught fish. The risk assessments are based on dose response functions for the Benchmark dose, which is defined as the dose at which the risk of a 5% chance of an adverse neurological effect can be demonstrated. The risk assessments showed:

- Risks are small to the general population. Even in the vicinity of the power plant where deposition could double, risks to the general population remained less than 1 in 10,000. Doubling of local deposition increased risks by less than a factor of 10.
- The population risk is borne by less than 0.1% of the general population and less than 10% of the subsistence fisher population. This implies that only the high end consumers that are unfortunate enough to consume fish from the high end of the Hg concentration distribution are likely to have any appreciable risk.
- The population risk is much more sensitive to fish consumption rates than additional deposition from the coal-fired power plant. Estimated risks for subsistence fisher populations for the background deposition rate were more than an order of magnitude greater than for the general population at 2 times the background deposition rate.

The prediction that risks resulting from Hg emissions from coal-fired power plants are small for the general population and the fact that the risks are borne by a small fraction of the population suggests that placing reduction in mercury emission goals on a plant by plant basis will do little to improve human health. Therefore, a cap and trade approach appears to be acceptable from a risk standpoint. Although, the two plants analyzed have high mercury emission rates, this would need to be verified for different types of plants (e.g. lower stack heights) and emission rates and through measurement of Hg concentrations around the plant. However, the prediction also indicates that fish mercury levels may increase to concentrations above regulatory advisory limits near the plant. If this is substantiated through data collection, there may be justification for plant specific emission limits.

Although model projections were based on computer models that are regularly used to model local deposition effects, efforts should be made to validate the models through data collection near power plants. If the data suggest that the models do not closely match the deposition patterns, improved local deposition modeling should be considered. Also, if fish concentrations near coal-fired power plants are an issue, sampling of fish tissue in lakes and other water bodies within 5 – 10 km of the plant should be measured and compared to regional background values.

REFERENCES

Burger, J. (1998) Fishing and risk along the Savannah River: Possible Intervention. *J. Toxicology and Environmental Health, Part A, 55*: 405-419.

Bucholtz, S. and R. Lutter, (2002). An Epidemiological Investigation Into the Determinants of Mercury Concentrations In Fish, Brookings Institute, January 2002.

EPA, 1995. U.S. Environmental Protection Agency, (1995) "User's Guide for the Industrial Source Complex (ISC3) Dispersion Models, Volume I – User Instructions", EPA-454/B-95-003A, Office of Air Quality Planning and Standards Emissions, Monitoring, and Analysis Division, Research Triangle Park, NC.

EPA, 1997. " Mercury Study Report to Congress, Vol. III: Fate and Transport of Mercury in the Environment," United States Environmental Protection Agency, EPA-452/R-97-005, December, 1997.

Jacobs, H.L., et al. (1998) Estimates of per capita fish consumption in the U.S. based on the continuing survey of food intake by individuals (CSFII). *Risk Analysis 18*:283-291.

Landis, M.S. Assessing the Atmospheric Deposition of Mercury to Lake Michigan: The Importance of the Chicago/Gary Urban Area on Wet and Dry Deposition." Ph.D. Dissertation, University of Michigan, 1998.

Krabbenhoft, D.P., James G. Wiener, William G. Brumbaugh, Mark L. Olson, John F. DeWild, and Ty J. Sabin "A National Pilot Study of Mercury Contamination of Aquatic Ecosystems along Multiple Gradients" U.S.G.S. Toxic Substances Hydrology Program--Proceedings of the Technical Meeting Charleston South Carolina March 8-12,1999--Volume 2 of 3--Contamination of Hydrologic Systems and Related Ecosystems, Water-Resources Investigation Report 99-4018B

NAS, 2000. Committee on the Toxicological Effects of Methylmercury, *Toxicological Effects of Methylmercury.* National Academy Press, Washington, DC, 2000.

Stern, A.H., Korn, L.R., Ruppel, B.E. (1996) Estimation of fish consumption and methylmercury intake in the New Jersey population. *J. Exposure Analysis and Environmental Epidemiology 6*: 503-525.

Sullivan, T.M., P.D. Moskowitz, F. Lipfert, and S. Morris, (2001) "Potential Risk Reduction Arising from Reduced Hg Emissions from Coal-fired Power Plants." BNL report.

Sullivan, T.M., P.D. Moskowitz, F. Lipfert, and S. Morris, (2003), "The Impacts of Mercury Emissions from Coal Fired Power Plants on Human Health Risk " Progress Report for the period of March 2002 – March 2003," BNL Report in press.